

# Novel Ultrasound Sensor and Reconstruction Algorithm for Breast Cancer Detection

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# **Novel Ultrasound Sensor and Reconstruction Algorithm for Breast Cancer Detection**

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## **Abstract**

Mammography is currently used for screening women over the age of 40 for breast cancer. It has not been used routinely on younger women because their breast composition is mostly glandular, or radiodense, meaning there is an increased radiation exposure risk as well as a high likelihood of poor image quality. For these younger women, it is calculated that the radiation exposure risk is higher than the potential benefit from the screening. It is anticipated that transmission ultrasound will enable screening of much younger women and complement mamographic screening in women over 40.

Ultrasonic transmission tomography holds out the hope of being a discriminating tool for breast cancer screening that is safe, comfortable, and inexpensive. From its inception, however, this imaging modality has been plagued by the problem of how to quickly and inexpensively obtain the data necessary for the tomographic reconstruction.

The objectives of this project were: to adapt a new kind of sensor to data acquisition for ultrasonic transmission tomography of the breast, to collect phantom data, to devise new reconstruction algorithms to use that data, and to recommend improved methods for displaying the reconstructions.

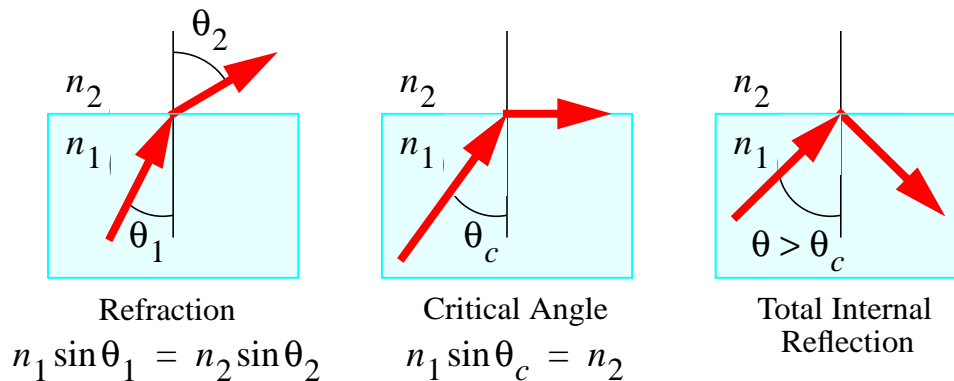
The ultrasound sensor images an acoustic pressure wave over an entire surface by converting sound pressure into an optical modulation. At the beginning of this project the sensor imaged an area of approximately 7mm by 7mm and was very fragile. During the first year of this research we improved the production and assembly process of the sensors so they now last indefinitely. Our goal for the second year was to enlarge the sensor aperture. Due to unavailability of high quality materials, we were not able to enlarge our original design.

We created a phantom of materials similar to those used in manufacturing breast phantoms. We used the sensors to collect data from this phantom. We used both established (diffraction tomography) and new (paraxial adjoint method tomography) reconstruction techniques to generate 3D images of the phantom.

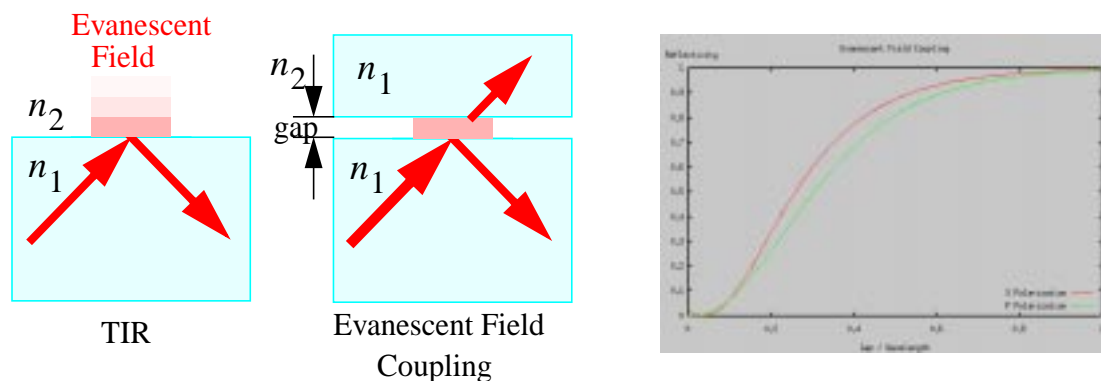
We also investigated techniques for displaying the reconstructions in ways that are readily comprehensible by physicians. Use of specific color densities and background grids was found to be most efficacious.

If implemented, this sensor will enable faster, more comfortable, and more sensitive mammographic imaging.

## Sensor Physics



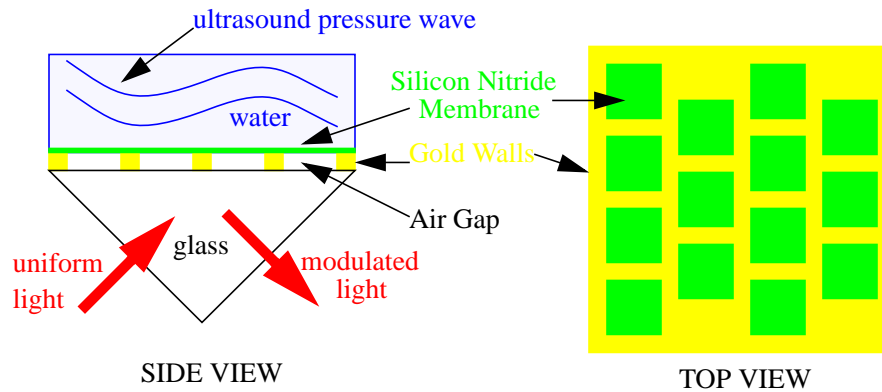
Refraction happens when light passes from a medium of refractive index  $n_1$  to another medium of refractive index  $n_2$ . If  $n_1 > n_2$  there is a critical angle,  $\theta_c$ , beyond which an incident light beam will not be transmitted. Beyond the critical angle 100% of the light is reflected by Total Internal Reflection (TIR).



An evanescent field extends into the low index region, falling off exponentially to almost zero within one wavelength beyond the interface. If another piece of high index material intercepts the

evanescent field, some of the light is transmitted (so less light is reflected). The amount of light reflected is very sensitively dependent on the size of the gap.

## Sensor Engineering/Fabrication



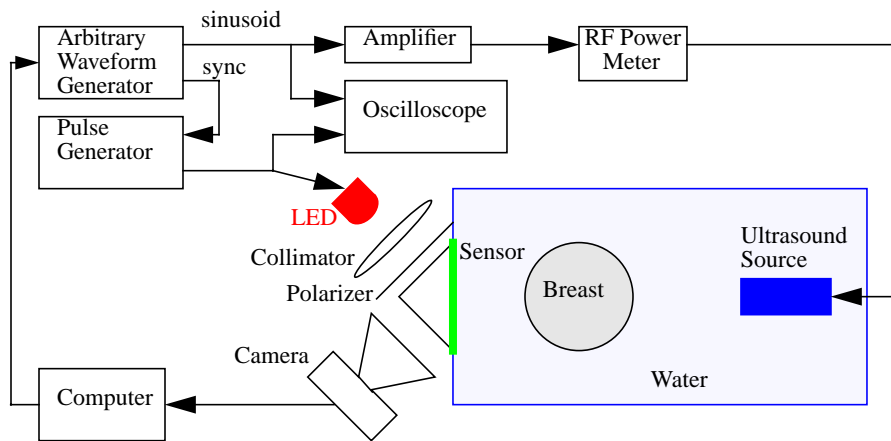
Light illuminates the sensor surface and is reflected from the air gap. When an ultrasound pressure wave hits the silicon nitride membrane it flexes. When the pressure is high, the membrane flexes toward the glass and the reflection is reduced. When the pressure is low, the membrane flexes away from the glass and the reflection is increased. The sensor images the pressure distribution over the entire plane. Each flexible piece of membrane acts as an acoustic pixel.



concentrations as the membrane tried to bridge the gap while under hydrostatic pressure in the water tank. No paned membrane survived exposure to the experimental environment.

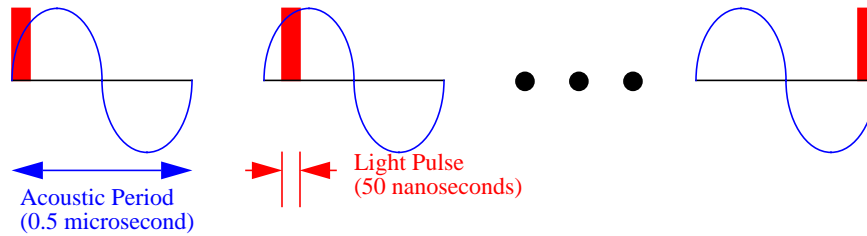
## Data Acquisition System

### Data Acquisition System Schematic



The Arbitrary Waveform Generator (AWG) produces both a sinusoidal wave at the acoustic frequency and a sync pulse that is used as the trigger for the pulse generator. The sine wave is amplified and sent to an ultrasound transducer. The pulse generator output is sent to a Light Emitting Diode (LED). The ultrasound insonifies the object of interest (a breast) and passes through to the sensor. The LED light is collimated, polarized, and illuminates the sensor. The reflection is modulated by the pressure distribution, captured by the camera, and saved by the computer (which controls the entire process).

## Strobing the LED for Pressure Acquisition



Just as a strobe light can be used to watch the vibration of a drumhead, we are using a strobed optical source to watch the relative phases and amplitudes of tens of thousands of acoustic pixels, all at once. Given a sequence of images and calibration data, we can extract the relative phase and amplitude of the vibration, and thus extract the relative pressure phase and amplitude at each acoustic pixel.

During the course of this project we have reduced the data acquisition time by a factor of 100. We started this project using an Apogee CCD camera with 16 bit pixels which required 1 second to acquire a frame of data and 8 seconds to offload it into the computer. We replaced the Apogee with a video camera and an 8 bit data acquisition board. We are now able to acquire video images at a rate of 10 frames a second. This has significantly changed the way we acquire data. Previously, we set the optical pulse at a specific acoustic phase for each image acquired. This added additional time to each frame acquired, but spread long term drifts in the data acquisition system parameters over all phases. This was important because it could take 3 hours to collect a sequence of data. Now we can set the optical pulse in the acoustic phase and acquire all the frames we wish to average (to increase the signal to noise ratio and make up for the loss of precision in an individual frame) in less than 10 seconds.

In addition to speeding data acquisition, switching to a video rate camera qualitatively changed the way the sensor can be used. We have found that at video speeds, the eye's averaging and filtering ability enables one to see changes in the pressure wavefronts impinging on the sensor in real time. By changing the timing of the optical pulse, one can infer the shape of the wavefront.

### 3 Fiber Phantom

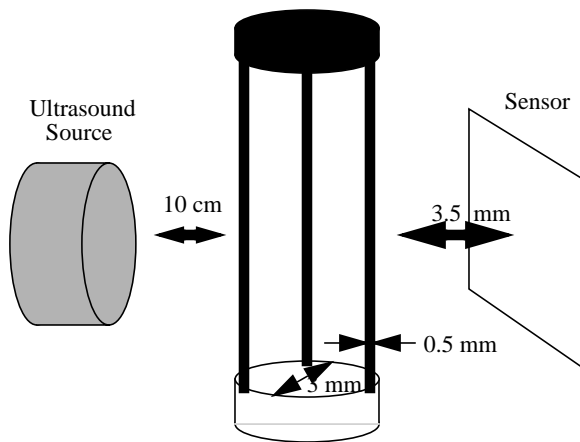
For a test of diffraction tomography using the data acquisition system we built a phantom with a constant 2D cross section. the phantom consisted of three pieces of 0.5 mm diameter fishing line placed at 120 degree separations around a 1.5 mm radius circle. These materials and configuration were selected because the plastic has an acoustic index not too different from the liquid medium (a situation that mimics the variability in acoustic index in the breast), and the sizes are



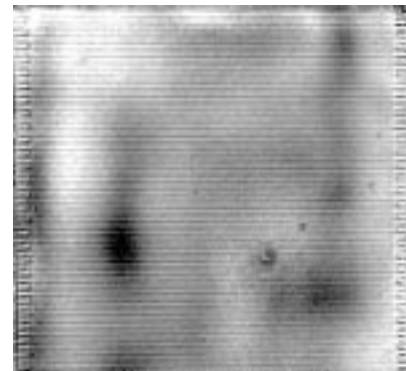
comparable to what we plan to image with the system. We used water as our acoustic medium, and an acoustic frequency of 2 MHz (and therefore had a wavelength of 0.74 mm). We determined that it would be possible to do a diffraction tomographic reconstruction with 18 views. We utilized a constant cross-section phantom so that 2D reconstruction (rather than 3D) could be performed. Full 3D algorithm implementations are still under development.

We modified the data acquisition system by adding a rotation stage above the tank and suspending the phantom 3.5 mm in front of the sensor. The rotation stage was manually controlled. We mounted the source transducer far enough away (10 cm) to illuminate the phantom with a planar 2 MHz ultrasound wave.

After data collection we had 18 projection sequences and 1 calibration sequence, each consisting of 10 images. For each pixel in every sequence, the intensity was fit to a sinusoid (with a phase) plus a background. Since the illumination over the optical field was not uniform (intentionally, to minimize costs), the sinusoidal amplitude was normalized by the background intensity. For every pixel in each sequence, we normalized the image of the projection ratios by the image of the calibration ratios, on a pixel by pixel basis. This yielded 18 images of relative pressure amplitude. By subtracting the calibration phase from the target phases, we obtained 18 images of relative phase



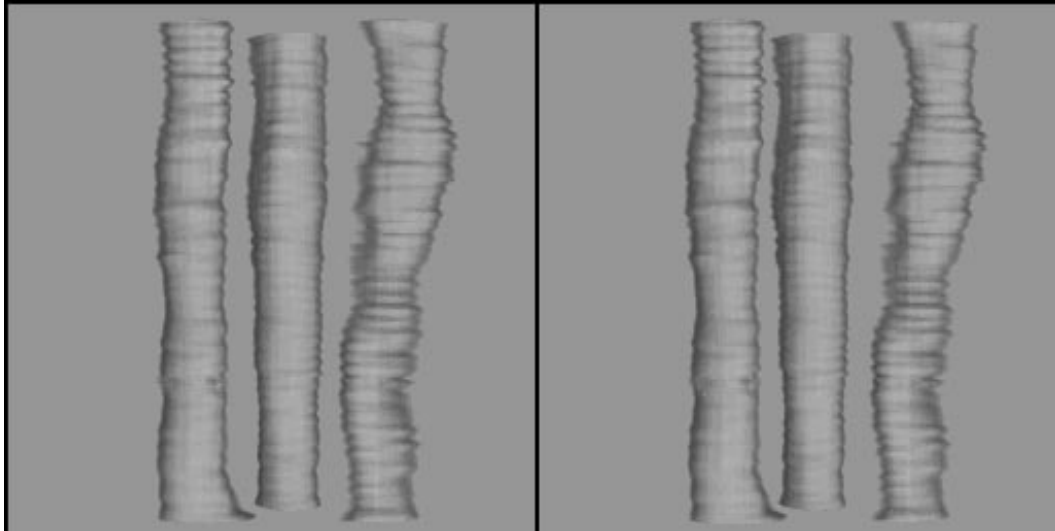
Experimental Setup



Relative Pressure Data From Sensor

We used the data acquisition system to collect ultrasonic transmission data from a phantom. The phantom was made from three pieces of monofilament fishing line. It was placed in front of the sensor and insonified by a beam of 2 MHz ultrasound (wavelength  $\sim 0.74$  mm in water). Eighteen views of this phantom were obtained. Each view consisted of ten images which were subsequently processed to extract images of the relative pressure amplitude and phase. The striations in the Relative Pressure Data are due to the fact that the sensor is made of rows of acoustic pixels.

## Volume Reconstruction



Right Eye View

Left Eye View

This is the result (in cross fusion stereo) of a 2 1/2 D reconstruction (using the Devaney-Rytov filtered backpropagation method) of the three filament phantom. The striations in the columns are due to the striations in the raw data that went into the reconstruction (see the figure in the Three Fiber Phantom section).

## New Reconstruction Algorithms

One of the goals of this project was to investigate new volumetric reconstruction algorithms. We developed an adjoint method reconstruction algorithm based around the paraxial wave equation. This is a nonlinear iterative reconstruction method. In a nonlinear reconstruction algorithm, a calculation is made of what data would have resulted from the current reconstruction (forward modelling). The output of the forward model is compared to the actual experimental data, and the difference is used to generate an update to the reconstruction. A one dimensional optimization is performed to determine how much of the update to apply. This involves many iterations of the forward model (which is why it is crucial to have a fast forward model). This process is repeated until the modeled data match the experimental data. The adjoint method is a fast and efficient way to generate the update to the distribution of the index of refraction we wish to determine.

To simplify the data processing we assumed that there was insignificant multiple scattering and no large deviations ( $> 10\%$ ) in sound speed occurred. This allowed us to use a paraxial wave equation solver for doing the forward modeling. A more correct forward model would have been a Helmholtz equation solver, but this would have been a much larger computational burden.

We were able to use the resulting reconstruction algorithm to do reconstructions from our three fiber phantom data. These reconstructions were comparable to those generated by diffraction tomography.

One advantage of the adjoint method reconstruction algorithm is that it can be easily extended to three dimensions. The basic core of the algorithm (the computation of the update) remains the same. Only the forward model must be changed to take into account the extra dimension.

## **Conclusions**

We have demonstrated the feasibility of evanescent field coupling as a means of sensing ultrasonic pressure and phase over an entire surface. By accurate reconstruction of our phantom we have demonstrated the potential for breast tissue sound speed and attenuation imaging with sub-millimeter resolution.

The next step in producing a clinical instrument is to modify the construction of the sensing surface to enable the manufacture of large area sensors.

## **Acknowledgements**

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